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20 METER RESOLUTION DEM OF LAKE BALATON AND ITS SURROUNDINGS – CREATION, IMPROVEMENT, APPLICATIONS

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Introduction

There are several ways for the researcher to obtain a Digital Elevation Model (DEM) of their area of interest. One is to purchase a database from a mapping and surveying authority. This is simple to carry out, because after specifying the area the authority can easily select it from its own national database and have it sent to the researcher. There are two drawbacks to this method however: price and precision. In terms of price there is great variability, nevertheless the fees are usually quite substantial. Precision depend on the level of detail the researcher requires for their studies, so they represent another problematic question. Authorities usually derive fine-resolution data from their existing coarser databases by direct interpolation, which means that no additional information is present in the newly created DEM, only the number of cells is increased.

In order to avoid these obstacles one often has to create their own DEM. This is cheaper (financially speaking) and much more accurate than the previous methods, though it requires a lot more effort. The present article demonstrates the creation and possible uses of a DEM representing most the Lake Balaton basin. The model includes about 95 % of the surrounding areas with elevation lower than 125 maB (metres above Baltic). The result iss a database that can be used in many fields of study, including geomorphology, archeogeology, illustration materials (**Figure 1.**) and so on. The second part of this article discusses some possible applications of the model.

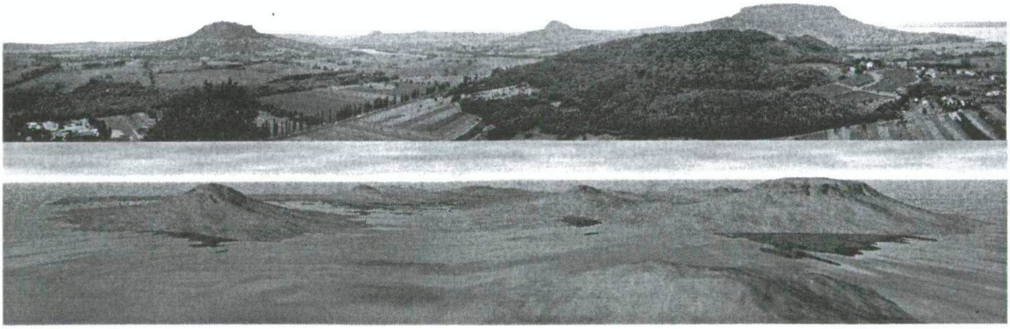

Figure 1. Above: panoramic photograph from Szigliget Castle
Below: the same area on the DEM with a hypothetical water level
(see Possible Applications)

Methods

The model was created through manual digitising of contour lines and spot heights. These data originated from the National Topographic Map Series (1971), partly because the whole national grid is available in the library of the Department of Physical Geography and Geoinformatics at the University of Szeged. **Figure 2.** shows the map sheets and what they became after about 2.5 years of digitising. This time may seem very long, but it includes earlier attempts to digitise portions of the area (Kis-Balaton and the Keszthely-mountains), which took much longer than expected. The actual digitising of the almost 30,000 km's of contour lines was done with assistance from several other GIS students at the Department. Thus the interpolation process could be tested and experimented using partial datasets evolving gradually. This opportunity proved to be very useful, because appending the sheets and checking for errors also took a long time. During this process many conditions were discovered which could cause some problems in the interpolation, these will be detailed later.

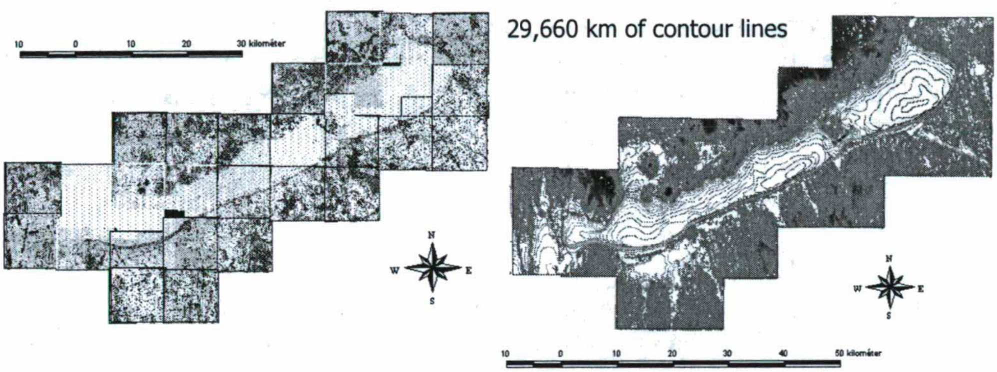

Figure 2. The used map sheets and the resulting contour lines (ESRI ArcView)

The sheets' scale is 1:25,000, they cover an area of 9.5×9.5 km with about 300 metres of overlap on the edges. The whole area contains almost 30,000 km-s of contour lines and more than 3,500 spot height data sources. The manual digitising of these data required about 1000 working hours, most of which was done using ESRI ArcView GIS 3.2. Geometric transformation was completed before digitising using Erdas Imagine 8.4. In order to be able to show perspective images with realistic texture an additional geocorrection was needed. This post-correction was done using 9-metre-resolution SPOT images found at the NGA GeoEngine website. These are available in WGS-84 co-ordinate system and GeoTIFF format, so they could easily be used in the process.

Creating the DEM

The DEM was created using the TopoGrid module of ESRI Arc/INFO. The original plans aimed a more detailed, 10-meter-resolution model, but due to the inadequate quality of source data only the 20-meter model was precise enough.

There were some minor corrections made afterwards, mostly because of the local morphological characteristics. The most apparent error was that the interpolator calculated a "trench" of app. 0.7-0.9 metres depth along the shorelines.

This happened because the lake-basin has slopes of about 0.5-1 %, while the closer surrounding terrain contains relatively steeper slopes (2-5 %) and the program often misinterpreted these data. To correct this error the model had to be interpolated in two parts: one was the lakebed bordered by the 1971 shoreline, and the other was the "rest", the surrounding hills and plains.

These two models were than combined into a database that aptly represents the artificial shores built along most of the lake. All the improvements up till this point have contributed greatly to the precision of the model, making it much more accurate than other DEM-s also created using digitised contours. Naturally, it cannot reach the level of perfection achieved by direct laser or radar measurements, but if there is no way to utilise such methods the advancements proved to be very usable and efficient.

The following section provides some hints about making the model more realistic, closer to the detail level expected from a terrain model. These "tricks" evolved through weeks of experimenting and produced quite spectacular results.

The resulting terrain models proved to be a viable substitute instead of laser and photogrammetry based technologies used in terrain modelling, which require sophisticated hardware and software elements.

Cliffs, Loess Walls

Due to the nature of the interpolation method the model in itself could not have abrupt changes in elevation such as quarries, cliff walls, etc. Instead it replaced these with long, gentle slopes, often more than 60-70 metres in length. The cliffs in real life produce elevation changes of about 20-40 metres in less than 5-8 metres distance, so the results from interpolation were far from the real features.

The cross-sections in **Figure 3**. show this problem. The continuous line shows the interpolated slope using the contour lines and spot heights. The dashed line represents what the model should look like: a step-like formation between the two areas of different elevation.

It is true that there are not many such formations along the lake, but these few (near Balatonföldvár, Balatonszárszó, along the south-eastern corner and in Fonyód) are quite impressive. This resulted in lengthy experimenting in order to achieve the cliffs' correct appearance in the model (**Figure 3**.).

The solution closest to reality came from the combination of two surfaces. One contains the low, the other the higher areas.

These two surfaces were merged along the digitised cliff line, which meant that the unwanted parts from the high area were replaced with the important regions of the low surface. The results of this method can be observed in **Figure 4.**

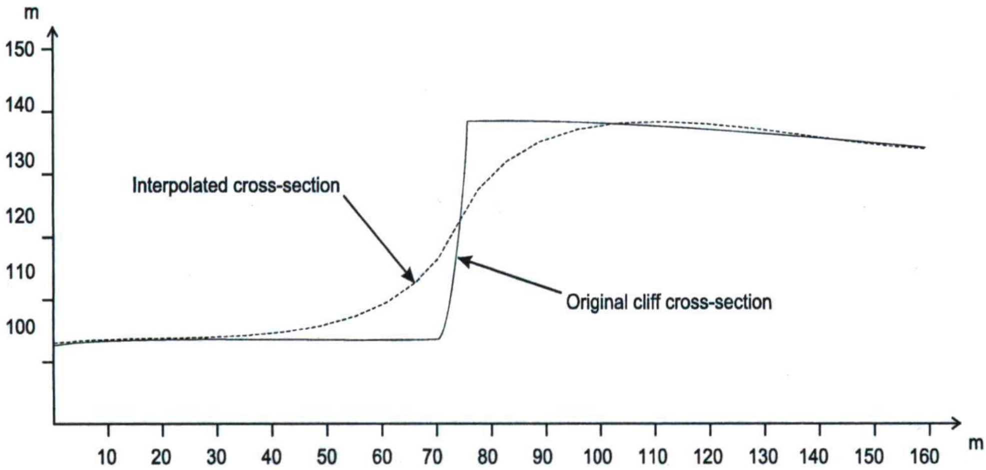

Figure 3. The problem with interpolation of cliffs and walls

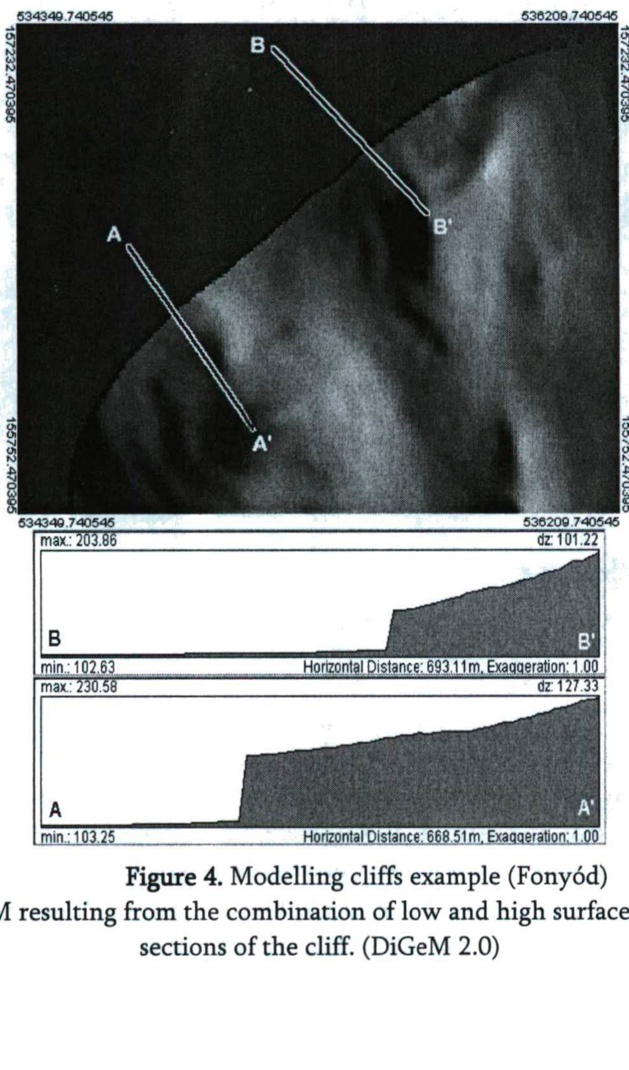

Figure 4. Modelling cliffs example (Fonyód)
Left: the DEM resulting from the combination of low and high surfaces; right: cross-sections of the cliff. (DiGeM 2.0)

Railway Lines Along Cliff Faces

The Budapest-Nagykanizsa and Budapest-Tapolca railway lines arrive to the lake's eastern shores approximately 40-50 metres above the shore level (140-155 maB), and gradually descend to about 108-110 maB along the shore over distances of several kilometres. This means a very gentle, long slope which is horizontal in the direction perpendicular to the rails on the edge of the cliff wall. The modelling of this structure involved almost every terrain-modelling technique: conventional raster interpolation, TIN surfaces with their raster conversion and raster arithmetics (performing mathematical and logical functions on surfaces). The resultant models contained every important feature (though some were a little exaggerated) with about 85-90 % precision.

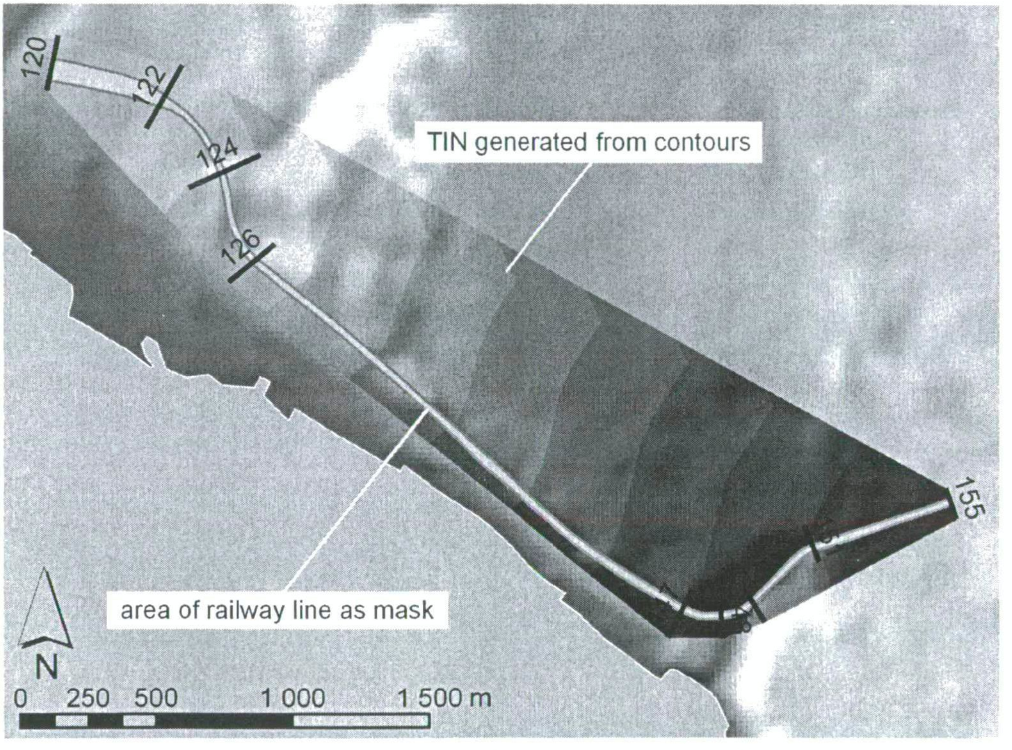

Figure 5. Steps of creating the railway line along the cliff at Balatonakarattya (ESRI ArcMap)

Figure 5. demonstrates the use of these techniques through the example of the Balatonakarattya-Balatonfűzfő railway line. First the slope of the rails had to be represented using contour lines so that they could define a 0.5-1 % slope. These contours were used to create a TIN (Triangulated Irregular Network: a surface modelling method which represents the relief with irregular triangles connecting points of known elevation.) surface which connects the lines with irregular triangles, forming a surface.

This method also solved the problem of straight slopes, because the artificial "terrace" of the railroad had to be as smooth as possible, and the TIN model could achieve this easily by placing flat triangles among contour lines. This TIN model then had to be converted into a raster dataset for further processing. The next step was to extract the width of the railway from this surface and to merge it into the original surface with the cliff already built in. The resulting cross-sections can be seen in the right side of **Figure 6.**

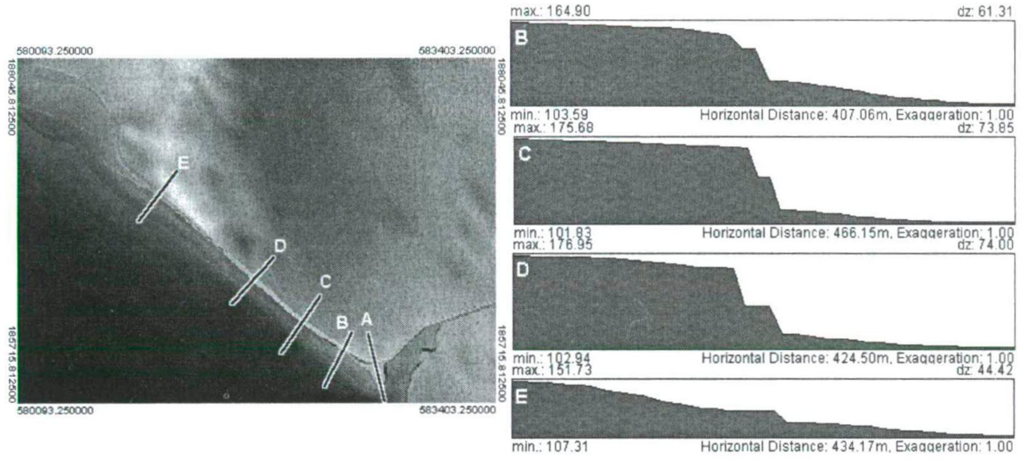

Figure 6. Railway line along the cliff wall; right: cross sections at the marked locations (DiGeM 2.0)

Quarries, Mines

The northern surroundings of Lake Balaton offer many opportunities for mining minerals or other resources. The two most important products were basalt and limestone.

Most of the limestone comes / came from the Keszthely mountains, while basalt originated in the volcanic "witness-hills" of the Tapolca basin and its neighbourhood.

Mining was almost completely terminated in the region, only a few quarries do still operate, most of them in the Keszthely mountains, (Cserszegtomaj, Gyenesdiás) producing limestone.

Some of the quarries and mines are large enough to appear in a 20-metre-resolution DEM, so in order to maintain precision, they should be included in it. The largest quarry-yard (with an area of approximately 75,000 m^2) is located in the E side of Badacsony, above the village. The basalt quarry was closed down in the late sixties, so many of today's holiday-makers can still remember the explosions.

As it is with the cliffs and walls, interpolation is unable to handle this kind of formation as well. The most satisfying method turned out to be a relatively simple one. The floor of these quarries is mostly flat and level, thus it can be represented with a polygon. This polygon would carry the elevation value of the floor-level and would be merged into the original terrain. Higher precision can be achieved if we use comparison operators, so that only such parts of the polygon would be inserted into the original model, that are lower in elevation than the terrain would have been without the quarry yard.

It is also possible to recreate multiple quarry levels by creating separate polygons for each elevation level. This method gives us the cross-section shown in **Figure 7.**

Possible Applications Of The Model

Evolution History

Lake Balaton has been studied intensely ever since the late 18th century. The most thorough and comprehensive research project began in 1920, when Lajos Lóczy initiated a program in order to increase our knowledge about the largest freshwater lake of Central Europe. The result: a 32 volume book series containing about 7000 pages and several map supplements. Most of this extensive work proved to be invaluable and valid even today. The findings in geology, hydrology and morphology gave much information about the origins and the formation of the lake, even if new theories emerge with time.

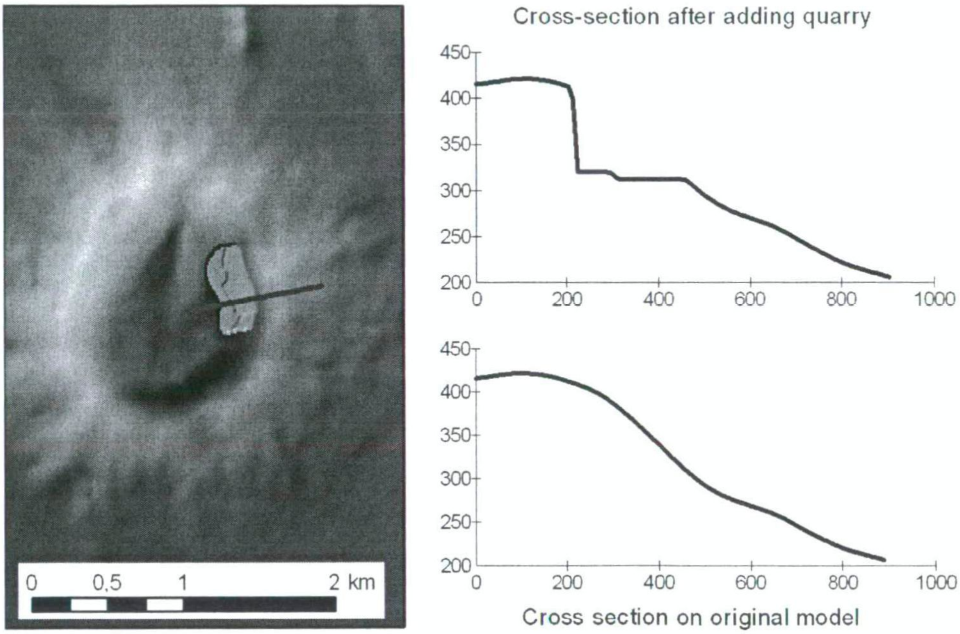

Figure 7. Cross-sections of the eastern side of Badacsony (see map on the left) without and with the quarry in the model (DiGeM 2.0)

A lake's life is best represented through the abrasion levels it leaves behind after the water level changes. These levels appear as step-like features in the landscape, with a narrow, relatively steep slope surrounded by gentler sides. The size of these levels can hint at how long the lake had that water level. Strong, well-visible levels indicate long times while shorter periods may not even show up as levels. Once these features are found scientists can obtain lots of information about the climate, vegetation etc. of the time when that water-level was existent. It is quite difficult to find these formations however, especially in densely populated areas. Lake Balaton has been a concentration point for many centuries and cultures. Generations lived one after the other significantly changing natural environment. This meant that many natural features were erased or modified, so that today only very few can be seen. The DEM proved to be a great help in identifying these formations being otherwise invisible or at least hard to notice.

Béla Bulla has discovered two abrasion levels of the lake in 1962. One of them (proved through measurements) is at 116 maB. The second one has not been proved yet, but many clues indicate its existence at 130 maB.

The present study aims to (among other goals) evaluate the potential of a manually created DEM in finding abrasion levels around Lake Balaton. At first we did not think that the model's resolution (20 m) would provide information about abrasion levels, but it turned out that we could pinpoint several potential sites. When we overlaid present day topography on the DEM and its derivations many more locations became apparent. The shape of settlements concurs significantly with our calculations concerning water cover of both recorded and theoretical abrasion levels.

The following example demonstrates the method through a very apparent location. The village Kéthely (6 km south from the lake) lies on the E side of a low hill-ridge.

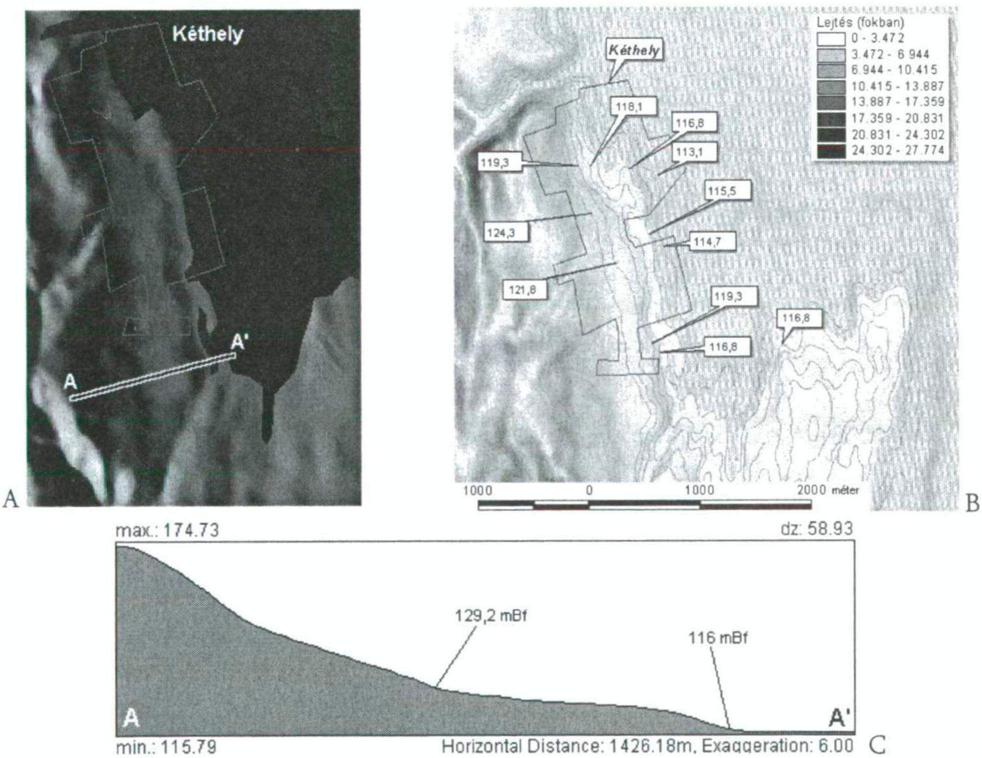

Figure 8/A Shaded relief with elevation as colour (blue: water at 116 maB); B Cross-section at marked location with suspected level heights (DiGeM 2.0); C Slope map with contour lines and calculated lake area

Near the southern edge of the settlement there is a structure that appears to be an abrasion level. **Figure 8/A** shows a shaded relief map of the area, with illumination coming from the southwest at a low angle.Contrast has been increased just to amplify the shades. It is clearly visible, that there is a relatively significant difference in slope values just at approximately 116 and 129 maB. If we compare this image to the profile taken along the specified line, it becomes evident, that at one time in the past waves broke here.

The above is just one very noticeable example taken from some 18-20 more sites identified in the DEM. Some are just as clear as the previous one, others are less obvious. Sometimes it takes other map coverages to point out the abrasion levels, but these 18-20 locations are all along the 115.4 – 116.7 m height. The following maps (**Figures 9., 10.**) show some more examples, when present day topography indicates possible water levels in the past. The maps contain the calculated extent of the lake for the abrasion level at 130 maB with blue dot pattern.

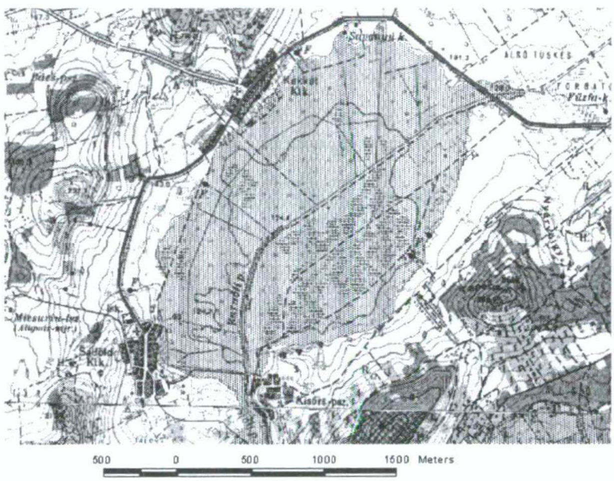

Figure 9. Káli basin – observe the road (red) at the edge of the calculated extent

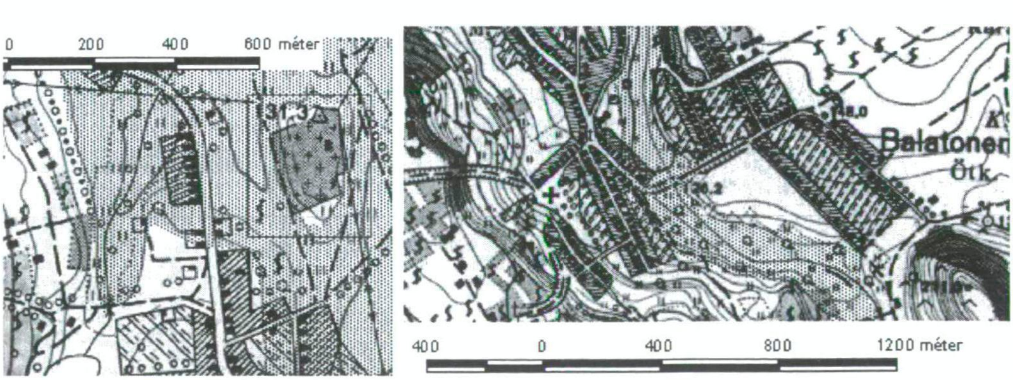

Figure 10. Left: cemetery of Látrány on the top of a 131-metre-high hill
Right: Balatonendréd divided by a small valley just under 130 maB

Tourism

Most of the northern neighbourhood of Lake Balaton is part of the Balaton Highlands National Park. There are many look-out towers in the hills from where the viewer can enjoy some breathtaking landscapes. The region does not provide the "amazingly overwhelming power of nature" kind of beauty but something more serene, relaxing and closer to our own size and scale.

Planning of look-out towers could use the elevation model very efficiently, since many software offer tools for visibility and line of sight analyses (**Figure 11.**). It is true that the model does not contain artificial features such as railway lines or dams, but the results of such examinations can pinpoint some candidate locations. These locations can be analysed more thoroughly afterwards and possibly prove to be excellent sites for the tower. The model also provides a great tool for the planning of scenic routes, from where the traveller can enjoy really nice vistas.

Visibility parameters also affect the placement and operation of cellular telephone antennas, thus their planning process can also utilise the DEM and the appropriate GIS techniques.

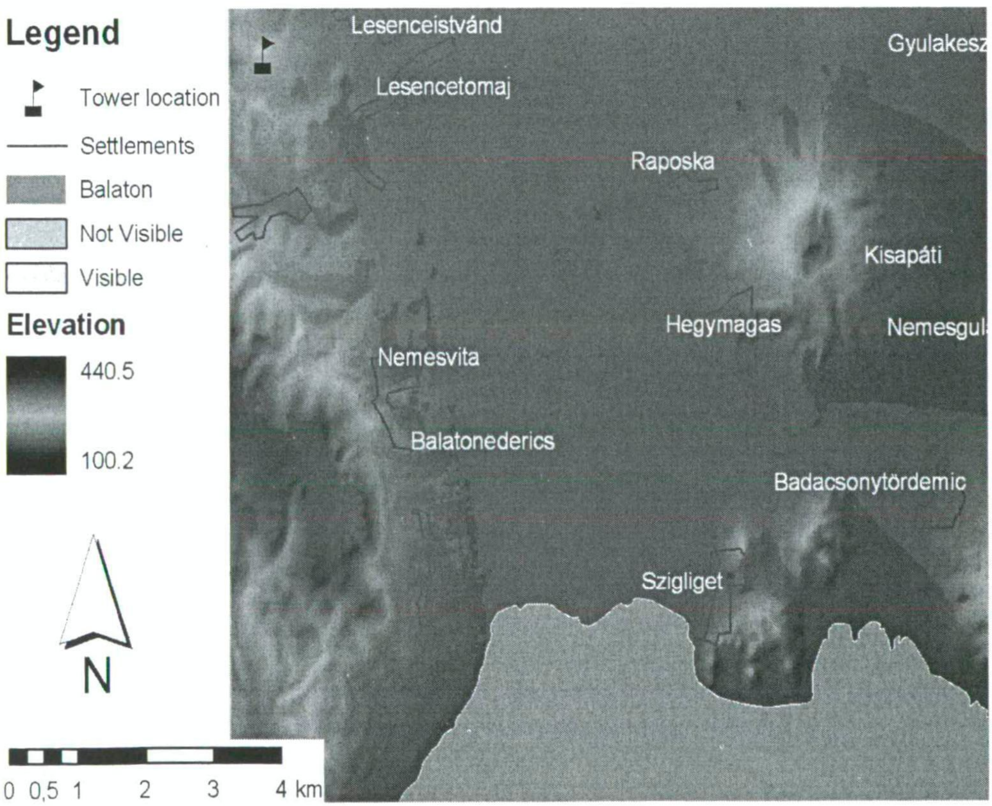

Figure 11. Example for visibility analysis: test site for lookout tower (ESRI ArcMap)

Illustration, Education, Advertisement

Today's computer technology offers excellent tools for the creation of virtual landscapes, terrains and to create the illusion in the viewer of being inside that virtual reality. Using this 3D technology the educator can provide students with exceptionally visual and attractive illustrations. This method can be used in many fields of study, for example geography, geology, history, morphology.

Apart from strict scientific usage there are also the more widely usable presentation applications. Even today's more sophisticated GIS programs (ESRI ArcGIS, Erdas Imagine) provide quite easy-to-use opportunities to create animations, so-called flyovers using the DEM data as a base surface. Of course many types of information can be draped over the surface, aerial photographs, orthographic imagery is used most frequently. These photos are usually large in size and require lots of computation to produce the 3D images. Another possibility is to use satellite images, but these are only usable for animations that "do not go too close to the surface". **Figure 12.** shows an example of the second method: 9-meter-resolution SPOT image draped over Taploca-basin.

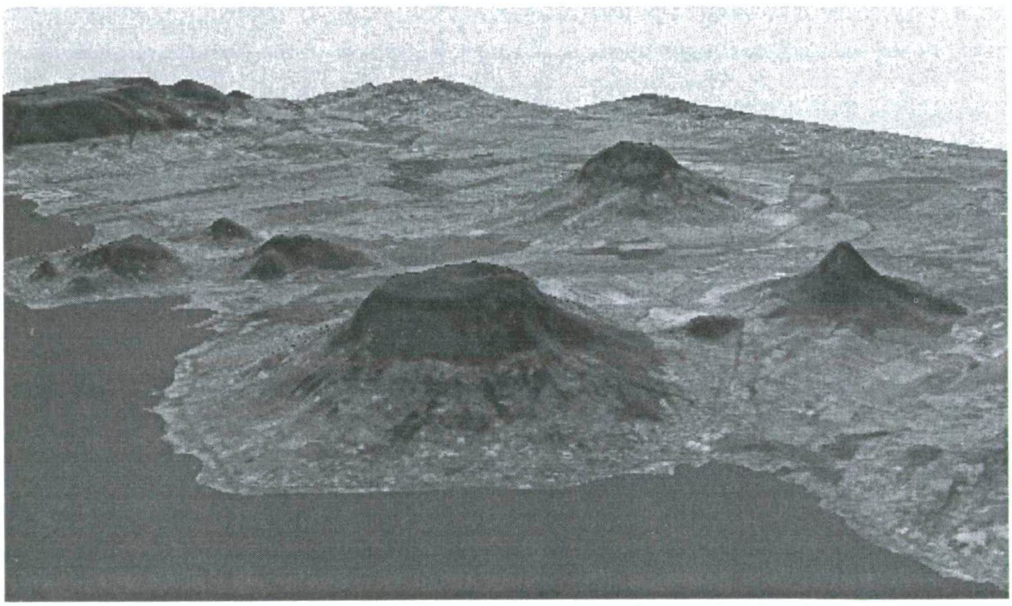

Figure 12. Panchromatic SPOT image draped over Tapolca-basin in ESRI ArcScene (Image from NIMA GeoEngine, SPOT 1992-1995)

It is of course also possible to drape any kind of data over the relief. The images can be enhanced by adding artificial objects (e. g. houses, dams, etc.) and even generalised forests or other natural features. These can be very useful in modelling a planned construction or to solve various problems (floods, wind energy assessment, etc.). In order to achieve this there are some other datasets needed, most often digitised by hand from topographic maps, aerial photographs or according to proposed plans.

An enhanced version of animations is when the viewer is able to see the terrain in 3D anaglyph mode, using red and blue or red and green glasses or, using more sophisticated equipment, true stereo visualisations. This is probably the most efficient way of displaying any surface model, because the viewer is completely deceived, embraced by the illusion of seeing the real terrain from an aeroplane.

Results, Conclusions

The current paper discussed the creation, refinement and possible applications of a Digital Elevation Model about the Lake Balaton area. The procedure of DEM generation revealed several problematic questions, which were solved by extensive experimenting. During refinement we were able to develop techniques to bring the model closer to real landscape features (cliffs, quarries, etc.) Thus the model became a very accurate representation of the research area.

In the second part we explored some application opportunities, including scientific research, illustration purposes, multimedia applications and the mapping of historic lake-levels. The examples show, that the model at its current resolution is capable of satisfying the requirements set by these functions. The most impressive results came from the modelling of historic changes and abrasion levels. This may prove to be of great assistance for geomorphologists looking for abrasion remnants signalling past extents of Lake Balaton.

More information and images available on the web at the following address:
http://www.geo.u-szeged.hu/~papesz/dem

References

BULLA, Béla (1944) A Balaton kialakulásáról és koráról, Földrajzi zsebkönyv 3-14, Budapest
BULLA, Béla – MENDÖL, Tibor (1962) Magyarország földrajza, Budapest
ESRI ArcGIS Online documentation system, 2001
SPOT images from NIMA GeoEngine (http://www.nga.mil/portal/site/nga01/)

Used Software

ESRI ArcView GIS 3.2 (3D Analyst, Spatial Analyst)
ESRI ArcGIS Desktop 8.2
ESRI ArcInfo Workstation 8.2
DiGEM 2.0
Corel Bryce 5.0 Demo Version

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